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Precision Pesticide Delivery Based on Aerial Spectral Imaging

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Abstract:

A prototype sprayer to deliver pesticides based on an aerial scan of a Nova Scotia blueberry field was developed and analysed. A program written in C reads the position from a GPS receiver and correlates it with a GIS file containing spraying information. GIS software used to create the files is generally ArcGIS software from ESRI but the program is also capable of reading a file from Idrisi Kilimanjaro from Clark's lab. The program finds and inspects all pixels under a nozzle spray during one second of travel based on the previous direction and speed of travel. The sprayer nozzles are turned on and off using solenoid valves. The solenoid valves and the GPS system use a 12 volt power supply so the entire system can be operated on a vehicle electrical system. The system is sensitive to positional error. Preliminary results using an off-the-shelf low cost receiver were positive. The presence of hills or the proximity to tree lines will cause positional error, which will reduce the accuracy of the system. The GPS receiver is a John Deere Starfire and with the SF2 differential signal has an accuracy of plus or minus 10 cm. The pixel resolution is roughly 1 meter.

Introduction

The implementation of precision agriculture is a growing area of research. Modern technologies such as high precision Global Positioning System (GPS) receivers, as well as powerful computers and sensors can enable farmers to keep track of factors such as crop yield, soil nutrient level, livestock movements and store these factors in databases for analysis. Furthermore, systems can be devised to correct deficient factors “on-the-go” with minimal human input.

Site specific spraying is a kind of precision agriculture that recognizes that field factors such as nutrient and moisture deficiencies, weeds and other pest infestation may vary significantly within a field. The wild blueberry industry of Nova Scotia, headed by Oxford Frozen Foods, recognized the need for precision spraying to reduce the amount of herbicide used on wild blueberry fields. Teamed with Dr. Percival and others under the Atlantic Innovation Fund program, Oxford Frozen Foods launched an initiative to create a precision spraying system based on spectral reflectance of the plants found in wild blueberry fields. While the end goal is to have an on-the-go sprayer using spectral or image sensors, the half way point of the research is to create a precision sprayer using a pre-processed, Geographical Information System (GIS) analyzed map of a field based on aerial imaging.

Literature Review

Thurston *et al.* (2003) stated that an important part of precision farming lies in GIS. Generally, GIS is used for analysis, simulation and model building purposes. John Deere and other agricultural manufacturers have used simple GIS software to generate data for yield mapping purposes (John Deere Literature, 2005). Schou *et al.* (2001) identified spraying needs for forest agrochemical applications and created a GIS program for decision support. Qing and Linvill (2002) have used GIS to simulate regional peanut yields. In these cases the GIS software is a tool for analysis and simulation and is not used for on-the-go chemical applications. Neméyi *et al.* (2003) used GIS as a decision-making and analysis tool. The most common usage of GIS is a tool for analysis of data.

GIS software has also been used for on-the-go systems, especially in variable rate application research. Larsen *et al.* (1988) varied the injection sprayer output based on a GIS map and a differential GPS receiver. The injection of the active ingredient was changed uniformly across the boom, based on the GIS map. Al-Gaadi and Ayers (1999) tested the accuracy and lag time of a variable rate, direct injection sprayer based on a GIS map. It was found that the reaction time was 2.2 seconds and with an application rate error of less than 1%. The project outlined in this paper extends the latter project by having each nozzle on the boom controlled separately, although still keeping the spraying rate of the active ingredient the same from each operating nozzle.

On-the-go sensing is an area of study that is rapidly gaining momentum. It is being investigated globally to determine whether the spectral classification of plants can be used to differentiate between weed and crop and to detect nutrient deficiencies. The management of nitrogen deficiencies in plants is the most common precision farming activity (Noh *et al*. 2003). Chen *et al.* (2003) have obtained satisfactory predictions by using multi-spectral imaging to determine the nitrogen content of rice crops. Noh *et al.* (2003) concluded that using a multi-spectral charge-coupled camera (CCD) could provide sufficient on-the-go information on nitrogen deficiency in corn. Tumbo *et al.* (2001) have created an on-the-go system for sensing chlorophyll at the low speed of 0.6 km/h. The same system did not provide useful results at significantly higher speeds. On-the-go systems are being investigated for their potential to detect and correct for other nutritional deficiencies. Adamchuck *et al.* (2002) showed that it is possible to detect the nitrate and potassium levels of soils using ion selective electrodes. Adsett *et. al.* (1999) found that by using ion selective electrodes, the soil nitrate level can be detected on-the-go to 95% accuracy after 6 seconds of measurement. Gillis *et al.* (2001) have successfully created a system that can detect and spray herbicides on weeds along highways. This system uses vision sensors and boomless spraying nozzles.

Tian *et al.* (1999) used real time image processing of spatial and frequency parameters to control solenoid valves on a spraying boom to apply agro-chemicals to a field on-the-go. The software was developed in C/C++. The system was successful at a speed of 4.2 km/h.

This paper reports on the development and testing of a precision sprayer for pesticide delivery based on a pre-processed GIS analysis of aerial spectral imaging. The objective of this research was to develop a program capable of reading a GIS map and correlating locations on the GIS file with GPS to determine the need for spraying based on the pixel definition of the GIS map. The program and equipment was then tested using different criteria to evaluate their accuracy.

Methodology

The development of the precision sprayer system occurred in three major steps; computer analysis, retrofitting and testing of a smaller garden pull-type sprayer, and finally the retrofitting and testing of a full size 6.1 meters boom.

An initial control program was generated for the computer analysis part of the development with its functions individual tested. Another program was created to simulated a tractor following a user-selected path across a virtual field. This part of the development was crucial in detecting and fixing problems encountered with the correlation between the coordinates of the map and the GPS. Also this step eliminated problems with the verification of the pixel under the boom over the one second of travel between GPS fixes.

The retrofitting and testing of a smaller prototype was carried out using a four-nozzle, garden, pull-type sprayer. This step was done to prove that conceptually the idea of a GIS based precision sprayer was usable in reality. This proof of concept sprayer was tested on a parking lot where sufficient view of the sky translated into a GPS fix with sufficient accuracy. The testing at this step was used to eliminate the problems associated with spray delay. Spray delay is defined as the time it takes for the water to hit the ground from the time the computer sends a signal to the solenoid valve to open.

The last step in the development of the precision sprayer is the implementation of the technology into a commercially usable system. The testing at this stage did not need to be extensive since the testing done at the proof-of-concept stage of development had proved the technology.

Full Scale System Requirements

The precision spraying system developed for Oxford Frozen Foods was designed to operate a six-meter boom with 13 nozzles. Each nozzle is operated separately and the initial requirement was that each nozzle be turned on or off, only with proportional control to be added at a later time.

The system must be easily operated from a laptop computer which would also record information necessary to compute the sprayed area of the field and the amount of chemical that had been sprayed. The sprayer is to be operated at a speed of 5.3 km/h.

The control program used to operate the nozzles reads an electronic map generated from a GIS program and receives information from a Starfire GPS receiver. In order for the program to be able to take different GPS input, the program reads GPS information from a RS-232 protocol line reading National Marine Electronic Association (NMEA) sentences. The location of the GPS receiver, along with the speed and direction of travel, determines which pixel of the electronic map the control program inspects to see if spraying is required. The control program must be able to deal with both geodetic and Universal Transverse Mercator (UTM) coordinates to ensure versatility when used commercially.

Spraying System

While conceptual testing was carried out on a retrofitted garden pull type sprayer, the sprayer used for this research is HARDI NL sprayer with a boom of 6.1 meter (20.3 feet) and a tank size of 300 litres (79 US Gallons). The pump is PTO operated and comes with its own pressure regulating system. The line from the pump is separated into three lines at the distribution valve, each line feeding a section of the boom. The two end sections of the boom have 4 nozzles while the middle section has 5 nozzles. A distance of 50 cm separates each nozzle. The nozzles are flat fan HARDI nozzles with a spray angle of 110 degrees. The recommended boom height for these nozzles is roughly half a meter. However, the boom height can be adjusted provided the new height is input to the computer program prior to spraying and must be unchanged during spraying.

Using a series of T joints, the line connecting the distribution valve to each section was then connected to each nozzle. A solenoid valve was fitted as close as possible to each nozzle. The solenoid valves are ASCO Redhat Next Generation normally closed valves. Each valve has a maximum operating differential pressure of 1034 kPa (150 psi). Flow calculations have been performed using the reported Cv value of the valve. The pressure loss across the solenoid valve using the reported necessary flow rate across the nozzle at 310 kPa (45 psi) is roughly 4 kPa (0.6 psi). These solenoid valves also operate on 12-volts and use only 2 watts to operate. Figure 1 shows the sprayer before and after retrofitting. The circuit used for the full sprayer uses solid-state relays obtained from Crydom Co. The controller is the USB-1208FS manufactured by Measurement Computing. The data acquisition unit (DAQ) has 16 digital outputs. Additional signal ports on the DAQ make it possible for different sensors such as a wind vane anemometer or speedometer to be added at a later time.

The control program was designed in C using LabWindows from National Instruments. Additionally an analysis program was designed, also using the C programming language, to read and display the information such as where the spraying occurred on the field and where the tractor traveled after the spraying. The control program was designed to read a file from two GIS programs; Idrisi Kilimanjaro from Clark Labs and ArcGIS software from ESRI. The Idrisi format stores the map information in a text file and the pixel values in a byte format, in a separate file. The ESRI exported text file stores both map information and pixel values in the same file. Both GIS File are read and temporarily stored in arrays prior to spraying. Additionally, to keep the program versatile, both UTM and geodetic coordinates can be used when loading the map. The control program extrapolates the position of each nozzle spray width over the one-second interval between each GPS fix. The program then transforms this position into a pixel number matching those of the electronic maps stored in memory. If a pixel is marked for spraying then the program sends a signal to the DAQ, which in turns will turn on the correct nozzle.

The factors that are used to extrapolate the spray width location include the nozzle angle, boom height, speed and the distance between the GPS receiver and the boom. Those factors are input by the user prior to spraying. The program is designed to not respond until all parameters have been keyed in.

Testing of Prototype System

The first tests were to determine the ability of the system to spray an area fully, accurately and precisely. Testing was done using a smaller pull-type retrofitted garden sprayer. Giant pieces of litmus paper measuring .62 by .45 meters were made and placed in chicken wire pouches on a known location of a parking lot. The parking lot was chosen for its accessibility and the unobstructed view of the sky thus ensuring an accurate GPS fix. Prior to testing, the parking lot was mapped so that specific locations on the parking lot had known coordinates with high accuracy. An electronic map was constructed using Idrisi GIS software with a spray patch of 1.28 by 1.28 meters. The corner of this spray patch corresponded to that of an intersecting parking lot line.

The litmus paper was placed in such a way that an area of 5 meters square was set out to record overspray with the exception of test number 3 where a larger area (6.67 meters squared) was made to record more overspray. The wind condition was reported by Environment Canada at Halifax International Airport (21 km from spraying site) as winds gusting up to 10 km/hr coming from the north. The computer program recorded when the nozzles were turned on during the test with the coordinates of the GPS fix. The data was tabulated and graphically compiled below. Areas of minimal spray pattern indicate areas of either drift or when part of the spray was moved by the wind resulting in an incomplete change in the litmus paper.

The conclusion of the first test was that an advanced time needed to be incorporated into the control program to account for the delay from the time of the electrical signal to the solenoid to when the spray reaches the ground. This time was an average of 0.57 seconds.

The second tests were to verify that the advance time added was indeed correcting for the discrepancies encountered in the first tests. Six cardboard squares, each representing four 50 cm pixels, were placed on a parking lot in two rows with the center of each pixel at a previously survey location. The prototype was then pulled across the two rows and the spray deposition was then observed. Since it was a clear day the spray would cause the parking lot to darken. The center of the spray deposition was measured from the center of the cardboard squares at each squared a digital picture were taken. Different angles of approach and different speed were also tested.

It was concluded that the program achieves its goal of spraying a pixel accurately at speed of less then 10 km/h. Also, it was found that the area of overspray for a small patch was quite large. The direction of travel had an effect on the shape of the area of spray deposition but the pixel was fully sprayed in all tests.

Results

The difference among the spray patterns of the three passes in the first tests (figures 2 - 4) can be easily explained by the amount of drift created by the wind, the GPS error and the spray delay error, which was not accounted for at the time of the test. Also the velocity of the sprayer was not consistent during the test since the vehicle was manually operated. Although the direction of approach was along a parking lot line, it was very difficult to have the car trace exactly the same path every time.

Although not the primary purpose of the test, the area of the pixel sprayed during the test was also recorded. The results are available in table 1. The control program is designed to turn on the nozzle when the boom travels over an area needing to be sprayed, regardless of overlap with the spray of the adjacent nozzle. In this test, depending on the exact angle of approach, a second nozzle was turned on for a brief moment. The analysis and control programs use the pixel as the unit area of measurement. Therefore, when a second nozzle was turned on, the pixel adjacent to the target spray pixel was partially sprayed but recorded as being fully sprayed by the programs.

In this test, the pixel size was approximately the spray width of one nozzle. When the spray area is greater than one pixel, the amount of overspray is a much smaller percentage than it was in the first round of tests. Similarly, the underspray, or the area of the spray pattern not sprayed, is also a smaller percentage.

The second tests results can be found in table 2. The distance between the center of the spraying patch and that of the designated spraying area was measured and compared to that of the estimated distance based on the computer analysis of the test. Also, the positional precision was measured and tabulated in table 2. It was found that some positional variability of the GPS receiver was between 0.25 to 1.95 meters. But those errors were not large enough to prevent the spray area being fully sprayed during the test regardless of direction of approach.

Conclusions

The developed precision sprayer delivered spray to the target areas successfully at a spraying speed of 5.3 km/h. The system becomes unreliable at higher speeds. The system can handle relatively high positional inaccuracies since the system will always choose to spray even if only a small patch needs spraying. The maximum positional inaccuracy will depend on the size of the pixel and the spray width of a nozzle. Tree lines and hilly terrain will degrade the suitability of the system to operate within the positional tolerance of the system. The tolerance of GPS positional inaccuracies of the system can be minimised by keeping the receiver in open view of the sky. Further correction can be provided by real time kinematics (RTK).

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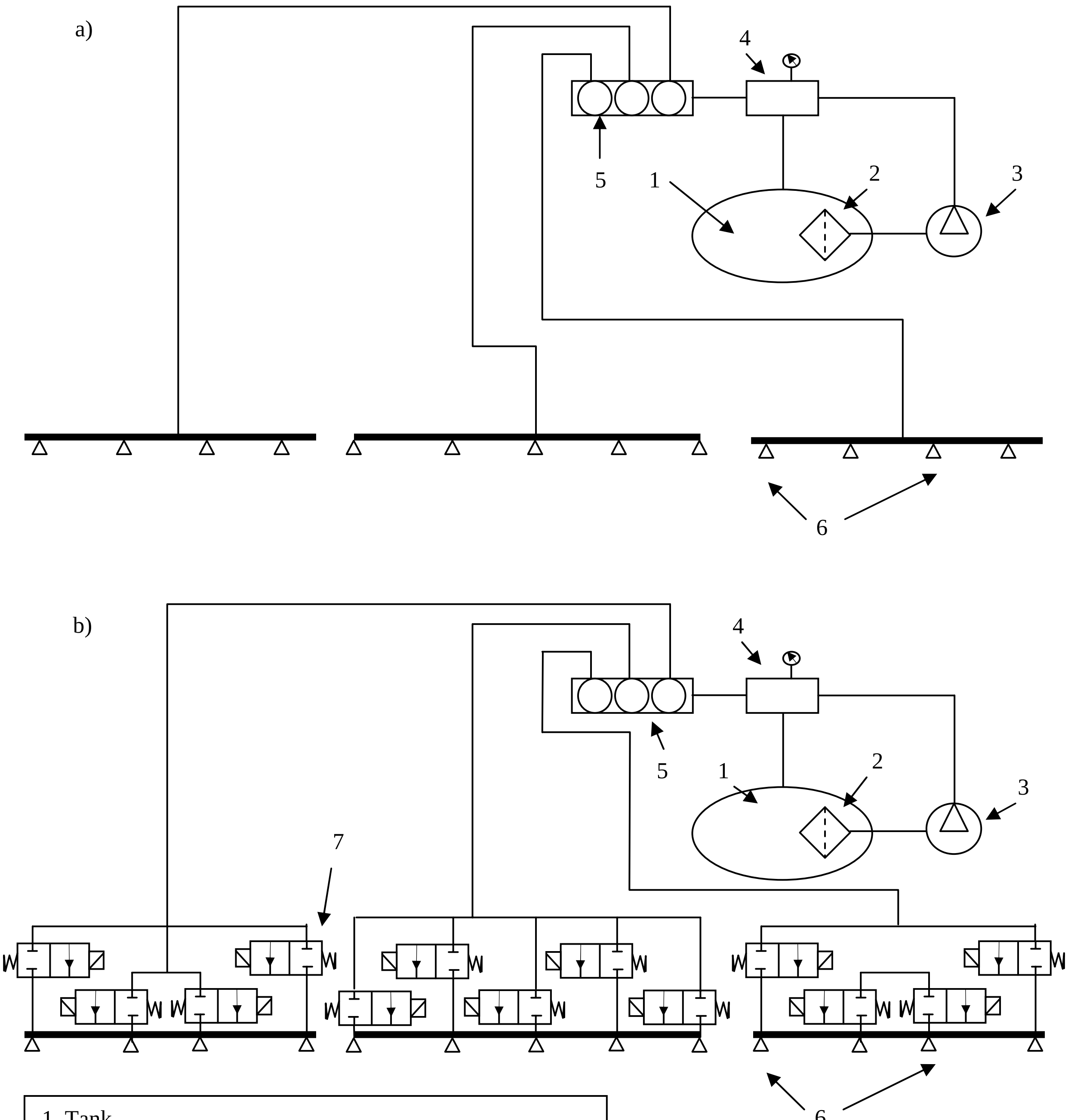

1. Tank
2. Suction Strainer
3. Pump
4. Operating Unit and Pressure Gauge
5. Distribution Valve
6. Nozzles
7. Solenoid valves

Figure 1 -- Modification to HARDI Sprayer, a)-Original b)-Modified

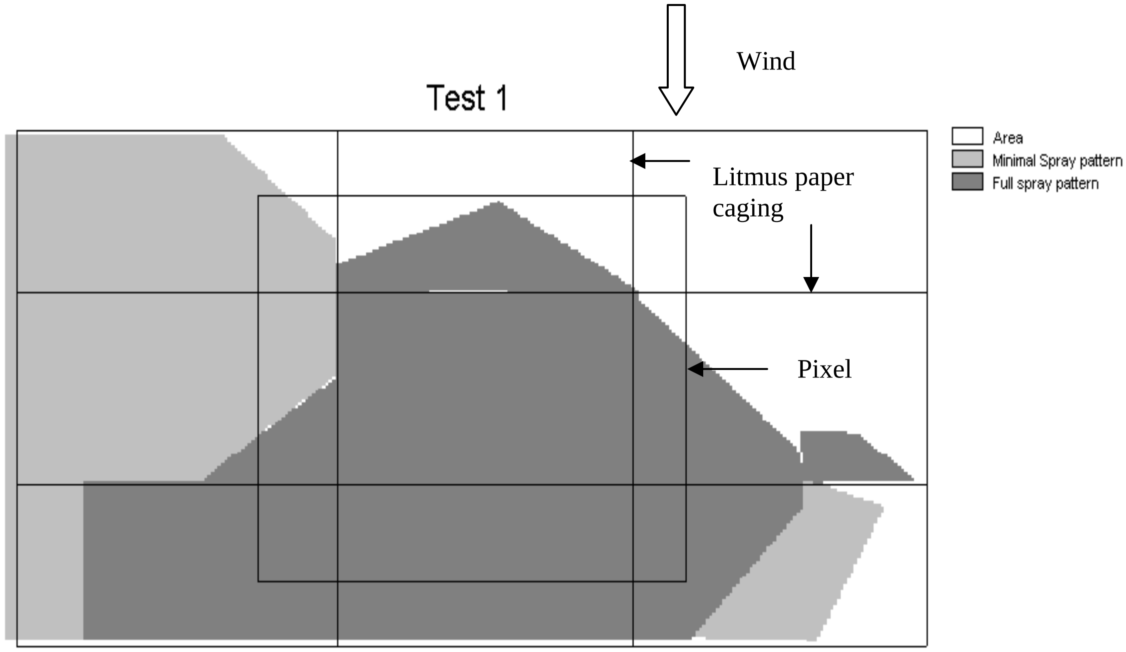

Figure 2 -- Graphical Depiction of Spray Pattern in Round 1 of First Test

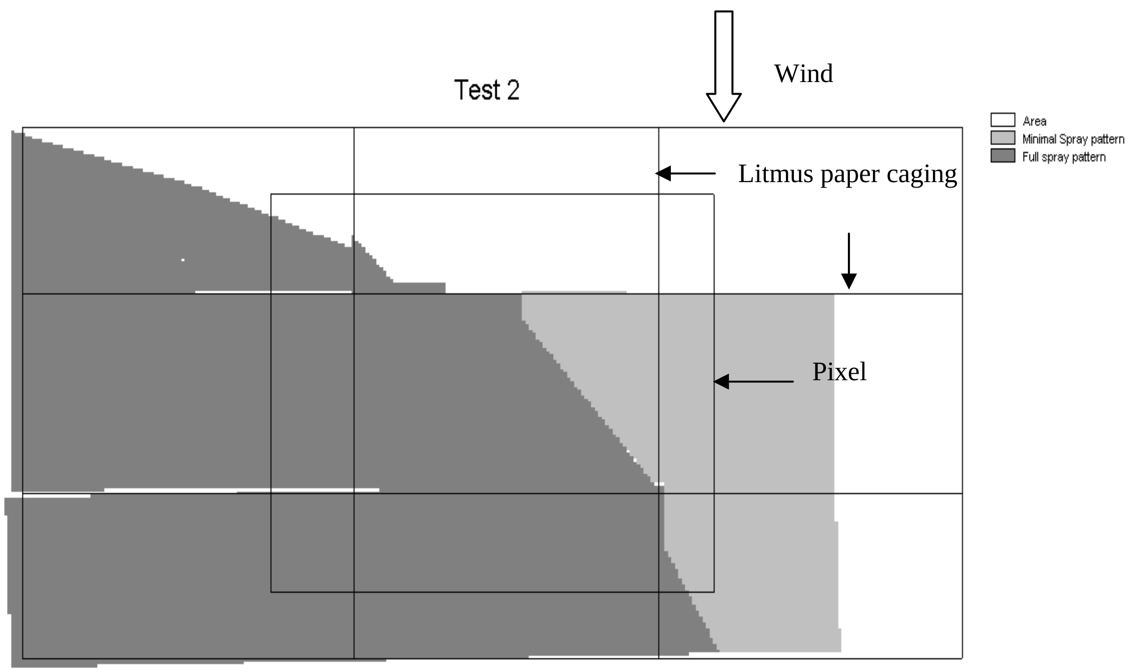

Figure 3 -- Graphical Depiction of Spray Pattern in Round 2 of First Test

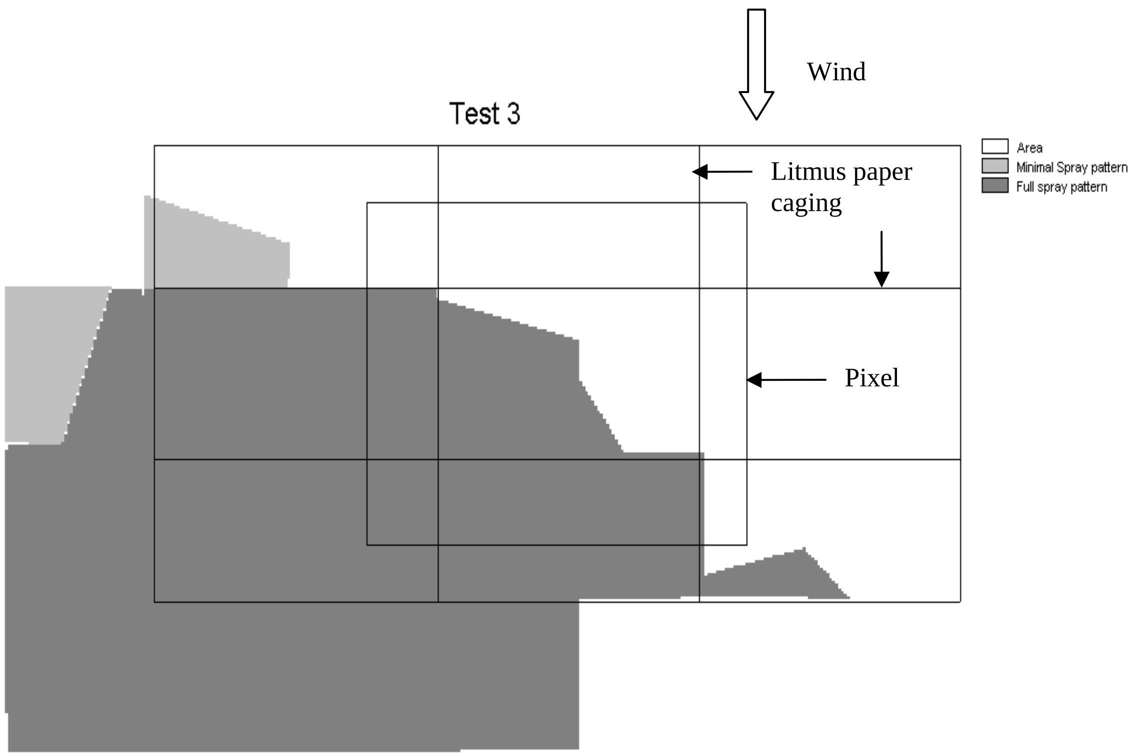

Figure 4 -- Graphical Depiction of Spray Pattern in Round 3 of First Test

Table 1 – Area Sprayed During First Tests in Squared Meters

	Test 1	Test 2	Test3
Total Recorded Area Sprayed	3.17	3.20	3.77
Area of Pixel	1.64	1.64	1.64
Area of Pixel Sprayed	1.42	1.26	0.74
Area Under Sprayed	0.22	0.38	0.89
Area Over Sprayed	1.76	1.94	3.03
Area Analysis Program Record as Sprayed	4.91	3.28	4.91

Table 2 – Results of Second Tests, measurement of GPS positional variability in meters

	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6
Max. Positional Variability on survey day 1 (70 points)	0.11	2.56	0.12	0.06	0.07	0.06
Max. Positional Variability on survey day 2 (70 points)	0.08	0.04	0.04	0.04	0.04	0.04
Max. Positional Variability on survey day 3 (70 points)	0.89	0.12	0.13	0.01	0.06	0.04
Max. Position difference from average position of all 3 days	1.38	1.26	0.93	0.70	0.63	0.42
Recorded difference between center of target spray pixel to actual spray pattern	1.25 @ 145º	1.16 @ 180º	0	1.25 @ 80º	.90 @ 135º	1.00 @ 90º
Estimated difference between center of target spray pixel to actual spray pattern	0.25 @ 90º	0.35 @ 210º	0.55 @ 180º	0.5 @ 90º	.35 @ 135º	0.50 @ 90º
Positional variability survey on day of testing	1.1 @ 270º	0.5 @ 315º	0.4 @ 225º	1.95 @ 315º *	0.56 @ 180º	0.67 @ 210º
Area of spray patch displayed by the analysis program	8.25 m^2	10.5 m^2	9.75 m^2	7.75 m^2	9.25 m^2	7.25 m^2

* The measurement taken for this point was done right after the GPS power had been cut off; it is possible that the receiver has not fully warmed up and thus gave a larger value.